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Investigation of index finger triggering force using a cadaver experiment: Effects of trigger grip span, contact location, and internal tendon force

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ABSTRACT

A cadaver study was conducted to investigate the effects of triggering conditions (trigger grip span, contact location, and internal tendon force) on index finger triggering force and the force efficiency of involved tendons. Eight right human cadaveric hands were employed, and a motion simulator was built to secure and control the specimens. Index finger triggering forces were investigated as a function of different internal tendon forces (flexor digitorum profundus + flexor digitorum superficialis = 40, 70, and 100 N), trigger grip spans (40, 50, and 60 mm), and contact locations between the index finger and a trigger. Triggering forces significantly increased when internal tendon forces increased from 40 to 100 N. Also, trigger grip spans and contact locations had significant effects on triggering forces; maximum triggering forces were found at a 50 mm span and the most proximal contact location. The results revealed that only 10–30% of internal tendon forces were converted to their external triggering forces.

1. Introduction

A trigger grip (or pistol grip) has been widely used to operate power hand tools. Approximately 40% of all industrial power hand tools can be categorized into trigger grip tools (e.g. nail guns, screw drivers, and drills) in the Ford Motor assembly system (Potvin et al., 2004). Trigger configurations reduce manual force requirements and task completion time and thus improve operators' performance and work quality. However, excessive and repetitive finger triggering may lead to *trigger finger*, a well-known cumulative trauma disorder (CTD), associated with repetitive finger works (Bonnici and Spencer, 1988; Nasca, 1980). The tendons in the finger with trigger finger become temporarily entrapped while sliding through their sheaths due to localized swelling and narrowing of the sheath. Trigger finger usually occurs on the volar side of the index finger (Oh and Radwin, 1993). If risk factors are not eliminated, trigger finger may advance to *stenosing tenosynovitis crepitans*, one of the more severe CTDs. Therefore, the proper design of trigger configurations is necessary to reduce excessive and repetitive finger motions.

The index finger is typically employed to operate most triggers on power hand tools (Oh and Radwin, 1993), and thus the index finger is more likely to be exposed to various work stressors (including forceful exertion, contact stress, awkward posture, vibration, etc.) caused by power hand tools (Oh and Radwin, 1993; Lin et al., 2001; Potvin et al., 2004). To reduce such biomechanical stresses on the index finger, experimental studies involving live subjects have suggested design guidelines for trigger configurations. Eastman Kodak (1983) reported that if the index finger is employed to operate triggers, its triggering forces should be kept low, preferably below 10 N, so as to reduce tendon loads in the index finger. Lindqvist et al. (1986) suggested that a trigger grip

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should be designed to allow use of the medial phalanges for operating to prevent development of nodules in the tendon sheath. Lee and Cheng (1995) investigated index finger's triggering forces as a function of different trigger grip spans and demonstrated that a 50 mm trigger grip span generated maximum triggering forces under the physiological tendon forces.

In vivo and cadaveric studies have investigated the physiological relationships between internal tendon tensions and external finger forces in various finger configurations. Schuind et al. (1992) examined the relationship between internal tendon forces and external finger forces in a pinch grip using an in vivo study. They reported that the flexor digitorum profundus (FDP) and flexor digitorum superficialis (FDS) carried 2.9 and 1.7 times larger forces respectively than their external pinch grip force. Valero-Cuevas et al. (1998) also investigated tip pinch grip using a cadaver study, and found that internal tendons (FDP and FDS) had approximately 4.1 times higher forces than their external fingertip forces. Park et al. (2009) found that total internal tendon forces (FDP + FDS) averaged 5.3 times higher than their external power grip forces in their cadaver study. More recently, Schweizer and Hudek (2011) conducted another cadaver study and identified that FDP tendon forces were approximately 3.3 and 3.0 times higher than external grip forces for crimp and slope grips, respectively.

The aforementioned studies still have limitations in terms of providing a comprehensive understanding between physical trigger grip design (e.g. trigger grip span and handle grip span) and physiological index finger triggering mechanism (i.e. force efficiency in the tendons). Live subject studies (Lindqvist et al., 1986; Oh and Radwin, 1993; Lee and Cheng, 1995) have suggested trigger design guidelines based on the relationships between physical design elements (e.g. grip span, grip length, etc.) and external triggering forces, to reduce work-related CTDs. However, internal tendon forces were not considered in their studies. Meanwhile, in vivo and cadaveric studies have investigated physiological internal tendon tension and external finger force, and concluded that the mechanisms vary depending on grip and trigger configurations (e.g. external force to internal tendon force ratio of 1.7–5.3). Nevertheless, physiological index finger triggering mechanism is still not completely understood. Therefore, a comprehensive cadaveric analysis on index finger triggering is needed to provide a better physiological and biomechanical understanding between internal tendon forces and physical design elements of a trigger grip. This could be useful for controlling work stressors and leading to better strategies for injury prevention from a biomechanical point of view.

We conducted a cadaver study to investigate index finger triggering as a function of different triggering conditions. First, an index finger motion simulator was built to control forearm-hand specimens and simulate the triggering motions of the index finger. Second, experiments were conducted to examine variation in external triggering forces as a function of (1) total internal tendon forces (FDP + FDS), (2) trigger grip spans, and (3) contact locations between the index finger and a trigger. Lastly, force efficiencies between external triggering forces and internal tendon forces were discussed based on the experiment results.

2. Methods

2.1. Specimens

Eight fresh-frozen right cadaveric forearm-hand specimens without apparent musculoskeletal disorders and anatomical abnormalities were employed in the study. The average age of the donors was 45.6 years (SD = 4.8). All specimens were harvested from male Caucasians and their anthropometric data were measured as shown in Table 1. The specimens were thawed overnight at room temperature (between 20° and 26°), and the wrist region on the forearm was dissected to expose the FDP and FDS tendons. The FDP and FDS tendons extending to the index finger were separated from the FDP and FDS muscle groups along with the layers distinguishing each muscle belly.

After the dissection, seven Schanz screws were drilled into the metacarpal (of the index finger), radius, and ulna bones on the specimens, in order to mount them into an index finger motion simulator. Four Schanz screws (4.5 mm diameter; 150 mm length; 45 mm thread) were embedded in the radius (one) and ulna (three) to secure the specimen in the simulator. Meanwhile, one short (2.5 mm diameter; 70 mm length; 20 mm thread) and two long Schanz screws (3.5 mm diameter; 175 mm length; 40 mm thread), driven into the metacarpal and radius respectively, were used to secure the specimen in the simulator through an adjustable wrist fixation system (WristJack, Hand Biomechanics Lab., USA). The wrist fixation system was installed on the radius side of the specimen to maintain the wrist at a functionally neutral angle, 20° extension, which allowed free for motions of all fingers (Li et al., 2001).

2.2. Index finger motion simulator

An index finger motion simulator consisted of four essential parts (Fig. 1): (1) support frame; (2) motion delivery unit; (3) data acquisition system; and (4) operating system. The support frame, consisting of aluminum T-slotted profile bars, was developed to secure and support the specimens. The frames were designed to help install necessary equipment such as fixtures and DC motors into the simulator.

The motion delivery unit was built to directly displace the tendons of the specimens. Two DC motor (Model IP66, 24 V, TiMotion Technology Co. Taiwan) linear actuators controlled cables (metal wire) extending to freeze clamps interfaced to the relevant tendons. The linear actuators were powered and controlled by an amplifier circuit and a USB DAQ 600 board (National Instruments Corp. USA).

The data acquisition system was composed of two parts: (1) multi-finger force measurement (MFFM) system and (2) tendon force transducers. The MFFM system was employed as a trigger grip to measure index finger triggering forces (Fig. 2); four miniature load cells (Honeywell International Inc., Model 13) corresponding to the index, middle, ring, and little fingers respectively were installed in the middle of the handle, and the handle grip (width = 15 mm; height = 45 mm; arc length of a trigger = 39.7 mm) was designed to adjust its span from 40 to 60 mm in 10 mm increments. The performance of the MFFM system was validated by Kong et al. (2012). Also, two force transducers (load cells; Model 247ST, KTOYO Co. Korea) were installed on the cables between the actuators and tendons. They measured internal tendon forces within the FDP and FDS, tendon slips to the index finger.

The operating system consisted of an amplifier, a USB DAQ 6008 board, and a customized operation software. The system was developed not only to collect index finger triggering force data from the MFFM system but also to produce feedback control of tendon forces through the force transducers and actuators. The customized operation software was programmed in LABVIEW (National Instruments Corp., USA). A vision system (HD Webcam C310, Logitech Corp., USA) was used to observe joint angles (on the sagittal plane) of the index finger during triggering.